AN OBJECTIVE METHOD OF FORECASTING SUMMERTIME STRATUS IN THE SAN FRANCISCO BAY AREA

BY

JOHN PAUL McMANUS

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App

PREFACE

This paper on San Francisco Bay Stratus has been prepared at the U. S. Naval Postgraduate School, Monterey, California during the winter and spring terms of 1951, for submission in partial fulfillment of the requirements for the degree of Master of Science in Aerology.

Acknowledgment and appreciation are due to Associate Professor Frank L. Martin for his assistance and guidance in preparing this work. Appreciation is also expressed to the Navy Weather Central, San Francisco, for making available the data used in this investigation and to Professor Aladuke Boyd Mewborn of the Department of Mathematics for consultation regarding certain phases of the statistical treatment.

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I. INTRODUCTION

The principal forecasting problem in the San Francisco Bay Area during the summer is the prediction of stratus clouds or "High Fog". This summertime stratus forms a low ceiling over the Bay Area for at least part of most of the days between April or May until October. Ground fog, however, is infrequent inside the Bay Area during this period.

In spite of the volumes that have been written on California stratus and stratus in the San Francisco Bay Area, there does not appear to be a good objective method of forecasting the occurrence of stratus. True, some forecasters with considerable experience in the Bay Area can predict this occurrence with a reasonable degree of accuracy. However newcomers, and in particular military forecasters who are continually being transferred to the Bay Area, are usually at a loss until some experience is gained. With this in mind, the author has undertaken this investigation with the purpose of establishing some "cut and dry" method of predicting the occurrence of stratus.

Most of the previous investigations have taken into consideration a multitude of parameters. Petterssen [6] has shown that there is high correlation between the base of the inversion and condensation level for the formation of stratus: the condensation level lying below the base of the inversion for the occurrence of stratus, and above the base of the inversion for the non-existence of stratus. He also showed that the stratus

ought to "burn off" early when the thickness between the base of inversion and condensation level is small and later when this thickness is larger. He attributed the formation of stratus to turbulent mixing in the layer below the inversion.

Neiburger [4] in 1944 in an investigation of three typical cases of Southern California stratus showed that advection of oceanic air may be an important factor in the formation of stratus over land but is not necessarily so. He showed that the cooling due to vertical motions causes stratus, and that vertical motions, reflected in the diurnal variation of the base of the inversion, was a result of sea breeze circulation. From these three cases he shows a maximum height of the inversion at about 0800 PST, and a minimum in the evening. He also shows that radiation from a moist but cloudless layer below the inversion is negligible in maintaining the base of the inversion but radiation from cloud tops will reduce the temperature at the inversion base and thus increase the inversion once the clouds have formed.

In 1945 Neiburger [5] made a more detailed stratus study for the period 17 July to 30 September 1944 and again showed the sea breeze to be the primary cause of the diurnal variation of the base of the inversion. He also stated that the problem of forecasting stratus consisted of two parts; forecasting the day-to-day changes in the height, temperature, and mixing ratio at the inversion base, and forecasting the diurnal variation of these quantities.

In 1948 Scripps Institution of Oceanography [7] investigated the diurnal variation of inversion height. There were found to be 575 cases

where the 0700 PST inversion was higher than the 2000 PST inversion, and 284 cases where the evening height was greater, a result which is somewhat at variance with Neiburger's diurnal oscillation mentioned above. Also in this investigation, many graphs and frequency curves were made of relationships between air-temperatures, dew-points and inversion heights.

All these investigations offered much data and theory but no "cut and dry" method of forecasting stratus. Probably the first objective method of forecasting fog was Taylor's fog prediction diagram [10] in 1917 which was a scatter diagram whose parameters were air-temperature at 2000 local and dew-point depression at 2000 local. This was for a radiation type of fog, and not quite applicable for Bay Area stratus.

Since it is well-accepted that the stratus is a result of warmer maritime air moving over cold water currents, the pressure pattern ought to be a parameter in the construction of a scatter diagram for predicting the occurrence of stratus. This parameter, along with the one and two thousand foot wind velocities, the height of the base of the inversion, and weather at the Farallon Islands were considered. Finally an objective method of forecasting stratus in the San Francisco Bay Area was arrived at and is herein presented. A reasonable degree of forecasting accuracy is possible by this method. It might also assist the experienced forecaster confronted with a borderline forecast. By this method the forecasting accuracy is much better than pure chance and also somewhat better than persistence.

The data used were the 3 hourly surface synoptic map as plotted every 3 hours by the U. S. Navy Weather Central at San Francisco, for the periods

May to October, 1949 and 1950 inclusive. In addition the daily pibals for 0700 and 1300 PST as recorded at the Naval Air Station, Alameda, and the daily 0700 PST Oakland radiosonde for the same period were used. The six-hourly surface synoptic maps for the Pacific and United States, as analyzed by the Staff, U. S. Naval Postgraduate School, were also used to obtain the over all large-scale synoptic situation.

This investigation is not complete as it stands due to limitation on availability of reports, since only 3 hourly surface synoptic reports were used. Hourly observations would probably yield better results. The application of this system to wintertime forecasting, along with time of formation and dissipation of summertime stratus would also make a subject for further research, and perhaps improvement of the forecasting.

II. DEVELOPMENT OF TECHNIQUES FOR FORECASTING BAY AREA STRATUS

1. The Stratus Season.

Summertime stratus or "High Fog" may form a ceiling over the San Francisco Bay Area anytime from April or May in the Spring until October in the Fall. (Steffan and Morgan [8]). Therefore this investigation will consider the months of May to October, inclusive, for the years 1949 and 1950. Stratus or "High Fog" is a most important weather factor during this time of the year. Fog, in the true sense, occurs very infrequently during this season, and actually becomes more common later in the year. (Steffan and Morgan [8]). During this period of stratus the maximum frequency occurs in the early morning at about 0700 PST and the minimum is in the mid-afternoon at about 1500 PST.

2. Causes of Stratus.

During the summertime the San Francisco Bay comes under the domination of two quasi-permanent pressure systems; the eastern lobe of the Pacific High, and the Thermal Low centered over the southwestern United States. However, Petterssen [6] has shown that this thermal low exists only near the surface and with increasing altitude, the low vanishes and a high level anticyclone at four kilometers dominates. This anticyclone can be considered as the eastern lobe of the Pacific High. From such a high there is a lateral outflow and a resulting descending motion. The descending motion heats the air adiabatically and reduces the relative humidity. Figure 1 shows a typical distribution of temperature and humidity as functions of altitude for Oakland, California. The cold moist air below the inversion

is usually referred to as the "Marine Layer", and is of Pacific origin. It is in this "Marine Layer" below the inversion that the stratus forms.

From Figure 2 we can see that there is an area of cold water along the California coast with a marked area of minimum sea-surface temperature north of San Francisco. Figure 3 shows the average summertime synoptic situation, and as can be seen the mean air current off the California coast is from the northwest. The sea-surface temperature is an important variable in determing the amount of modification which will be brought about in an overlying air mass. The trajectory of the air over increasingly colder water reduces the temperature of the air near the surface of the water. Moreover, having been in contact with the ocean the relative humidity is high. The cooling which takes place, together with convection due to turbulent mixing of nearly saturated air may result in condensation. As Petterssen [6] has shown, if the lifting condensation level is below the base of the inversion stratus will form, if above the base of the inversion stratus will not form.

Neiburger [4] has shown that radiation flux from the "Marine Layer" is insufficient to maintain the inversion. In fact heating rather than cooling takes place at the base of the inversion, provided no condensation has taken place. However, once the stratus has formed the radiational exchange is altered so that there is cooling, thus maintaining or even increasing the inversion.

From this, an explanation for the development of stratus over land is that it is carried inland at nightfall from the sea, over which it has formed.

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it is in this [illegible]

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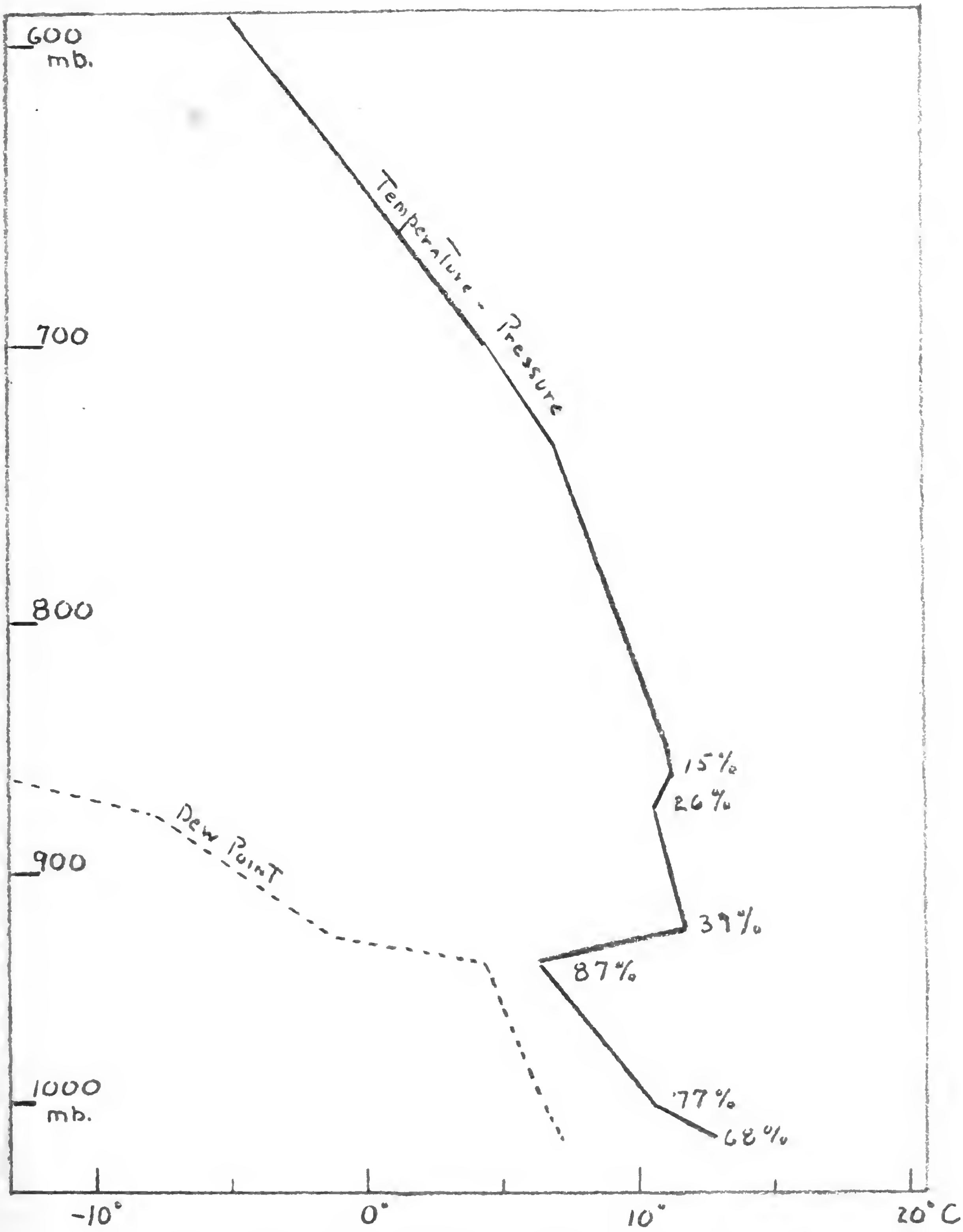
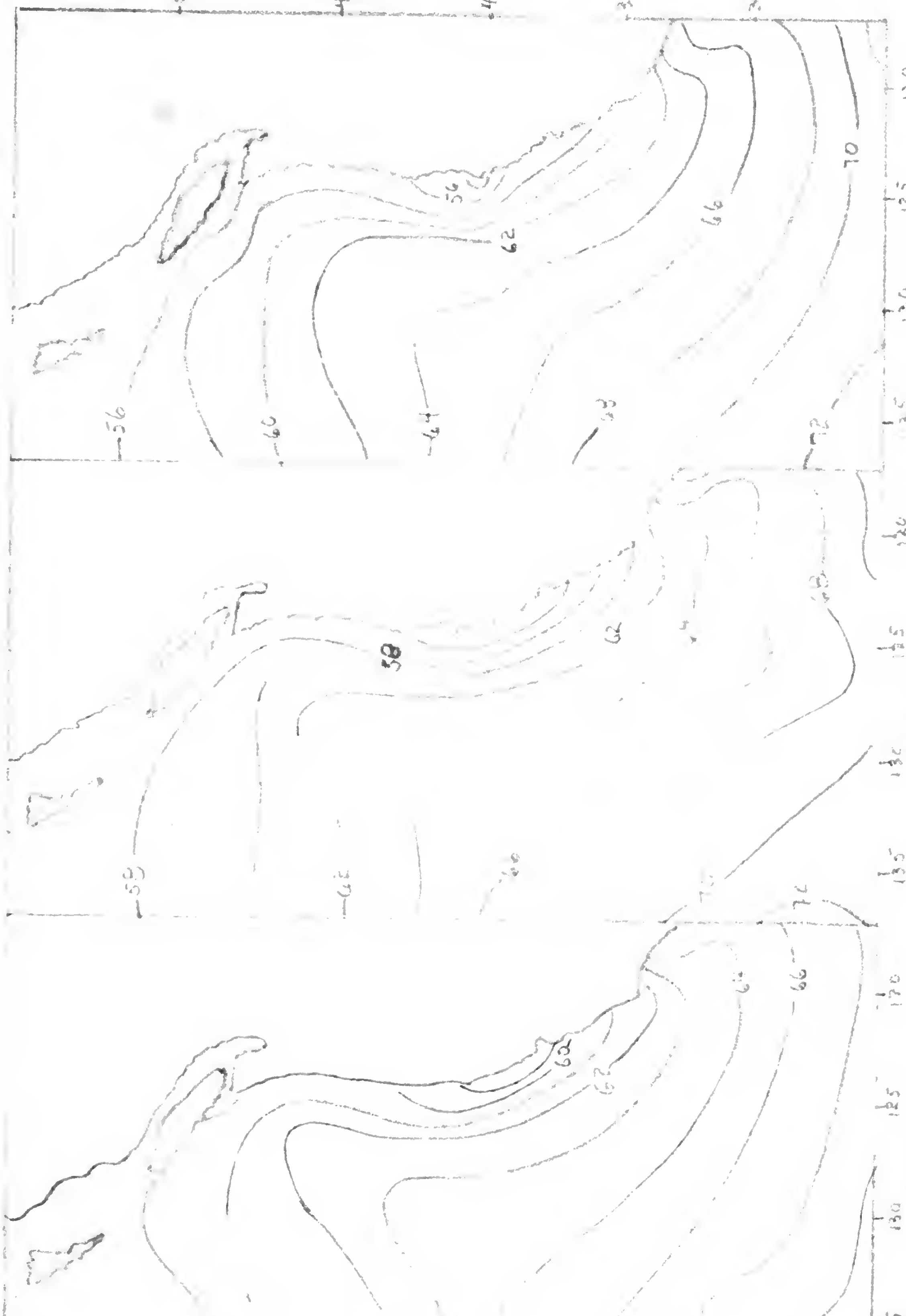


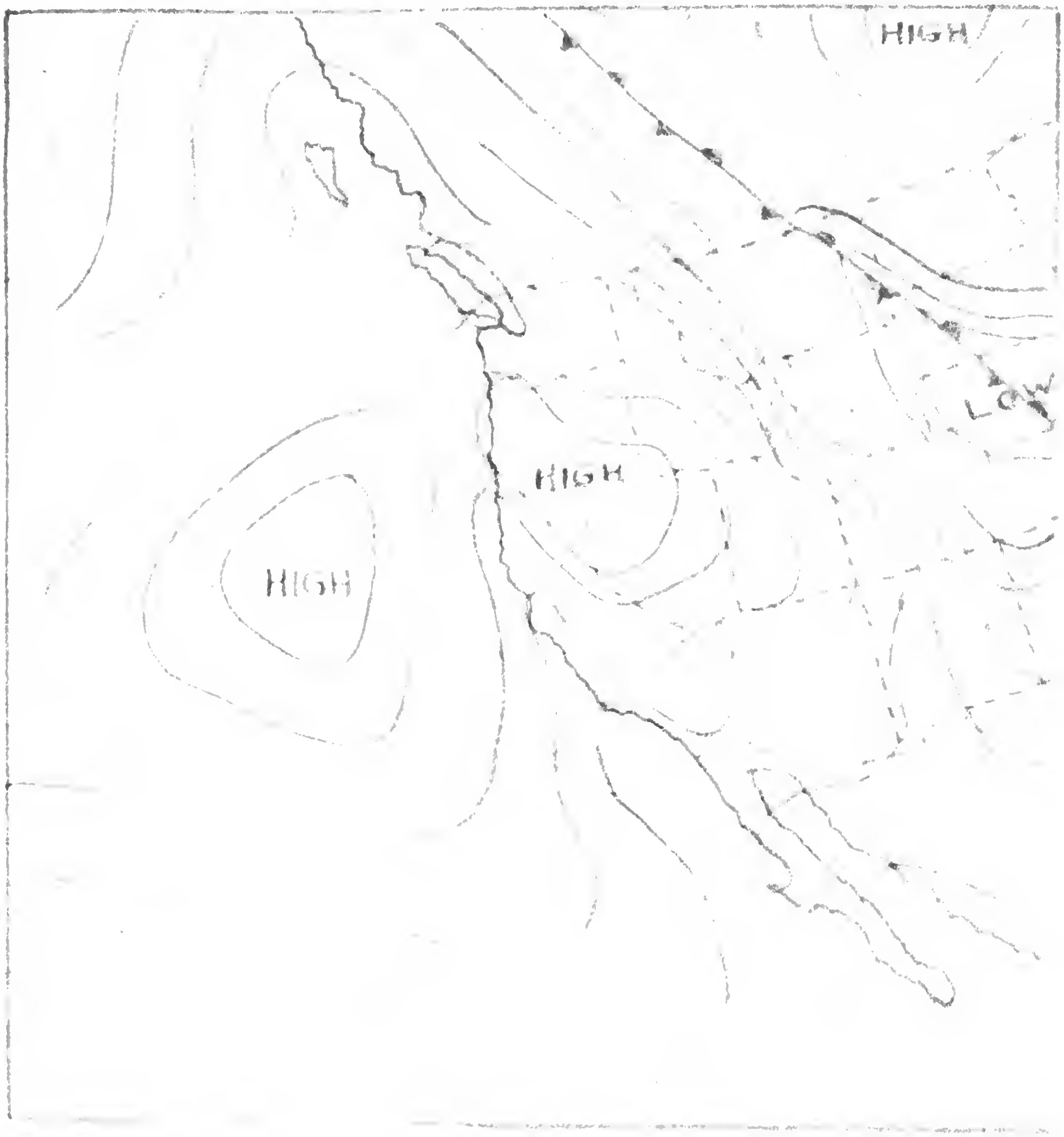
Upper Air Sounding at Oakland California
0300Z 7 June 1951

Figure 1



Average Sea Surface Isotherms

Figure 2



Average Surface Synoptic Map for Summertime

Figure 3

Neiburger [4] has shown that advection is an important factor for the formation of stratus. The other important factor is vertical motion causing adiabatic cooling. Neiburger attributes this vertical motion to oscillation of the inversion base caused by the sea breeze circulation. It is the author's opinion that this is plausible for southern California where tho normal pressure gradient is weak and where the sea breeze circulation is consequently strong. However, the author believes this vertical motion off San Francisco is due mostly to turbulence. The normal surface winds off San Francisco are stronger than those off southern California, and the sea breeze component is not as strong.

Another view relating to this is Byers' [1] . He describes in detail this advection process in connection with Bay Area stratus and states that the stratus is nearly always observed forming independently over the land. It is the author's opinion that this is true, if the lifting condensation level is below the base of the inversion, and that turbulence is increased as the air moves from the "smooth" ocean to the "rough" land, therefore causing condensation over the land. However, if sufficient turbulence is present in the marine layer to stir the moist air up to its lifting condensation level, the stratus should first form over the ocean and move by advection into the Bay area. This appears to be the experience of most forecasters in the Bay area. With this basic concept of advection as a primary cause, a main parameter involving the sea-level pressure pattern was employed, as will be shown in Section 4.

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Neiburger's mechanism for stratus formation is probably not the major cause in connection with Bay area stratus. In this area, the general circulation is stronger and the sea-breeze effect relatively weaker. Moreover, stratus is not a daily phenomenon in the Bay area, but rather exists in cycles of a week or so separated by several clear days and so can hardly be accounted for by a diurnal oscillation of the inversion base. In fact the latter disappears on occasion for several days at a time, exhibiting no appreciable diurnal effect. The major cause for stratus formation in these latitudes has been shown by Petterssen [6] and Stocker [9] to be identified with certain characteristic sea-level flow patterns. These will be discussed further in Section 4. Finally, the conclusion of Byers noted above does not appear to be in agreement with the experience of most present-day forecasters in the Bay area. However, this investigation does not concern itself with the small-scale question of whether stratus forms first over land or over the ocean, but presents a statistical treatment of the actual occurrence of stratus in the Bay area.

3. Local Factors of the San Francisco Bay Area Influencing the Stratus Formation.

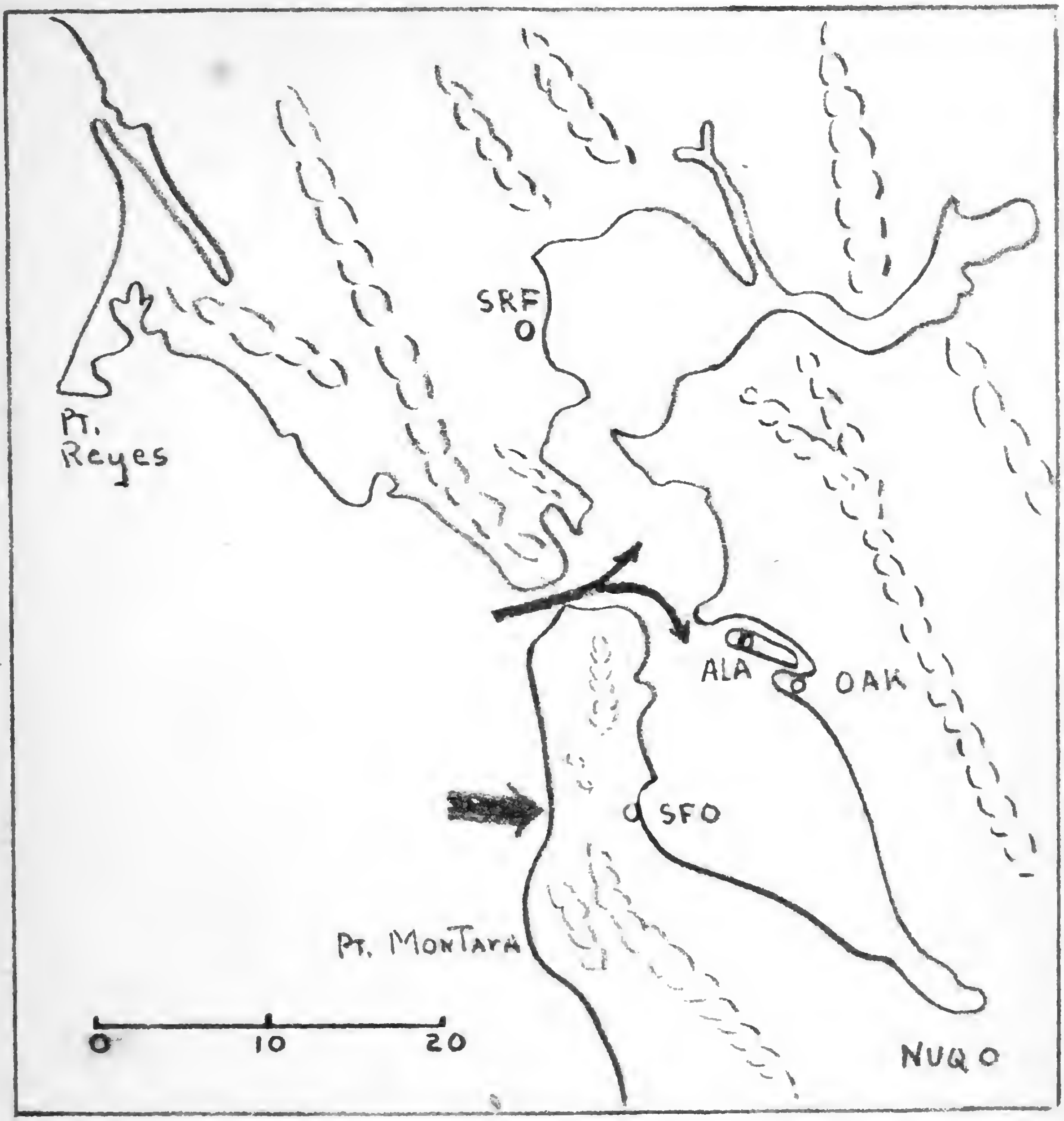
As was mentioned before one of the important local factors influencing the San Francisco Bay area is the sea surface temperature distribution off shore (Figure 2). As can be seen the coolest temperatures are just northwest of San Francisco, resulting in maximum cooling in this area and a high percentage of Fog or Stratus. From Figure 3, it can be seen the average summertime flow is from the Northwest over this cold water area. Therefore,

we should take into consideration the local topography of the San Francisco area to see how this cold moist air reaches the area. Figure 4 shows there are only two major breaks in the barrier of hills along the coast. One of these is the Golden Gate. The stratus that moves in this way usually covers the East Bay first, then spreads north and south and finally moves over the west side of the Bay. At other times the stratus will move over the Bay through the gap in the hills just west of San Francisco Airport. This gap is only 150 feet in elevation where the peaks to the north (San Bruno) rise to a height of 1325 feet and the hills to the south rise to 1400 feet. As to which one of these paths (or both, as often happens) the stratus will follow on a particular day is not considered in this investigation. The author is of the opinion that the path depends upon the inversion height and the direction and velocity of the mean wind below this inversion.

4. Synoptic Situation Affecting Bay Area Stratus.

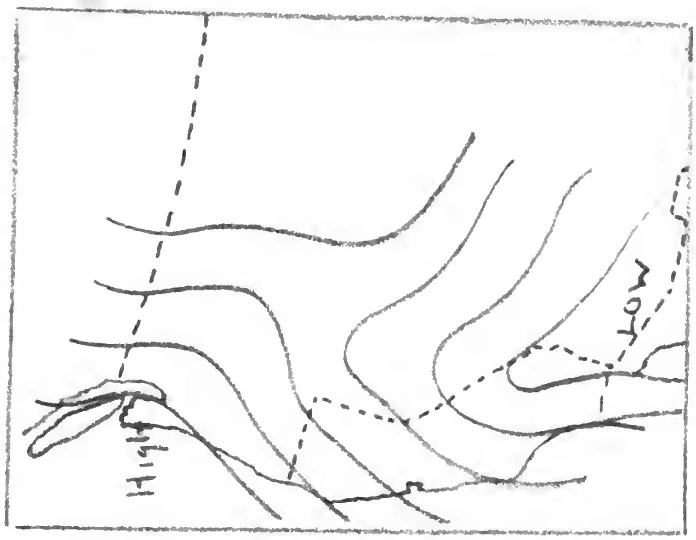
In Figure 3 is shown the average summertime surface synoptic situation. Figure 3 is an average map and thus Figures 5 and 6 (Stocker [9]) are presented. These show typical sea-level pressure patterns which favor either the occurrence or non-occurrence respectively. It was with these patterns in mind, that the author channeled his investigation toward arriving at criteria for these typical patterns and thus an objective method of forecasting. The pressure-difference diagram (Figure 7) is the result of this idea.

As can be seen from these flow patterns it is necessary to have a thermal low developed in northern California or Nevada. With a thermal low in this area there should be a typical pressure pattern in the San Francisco

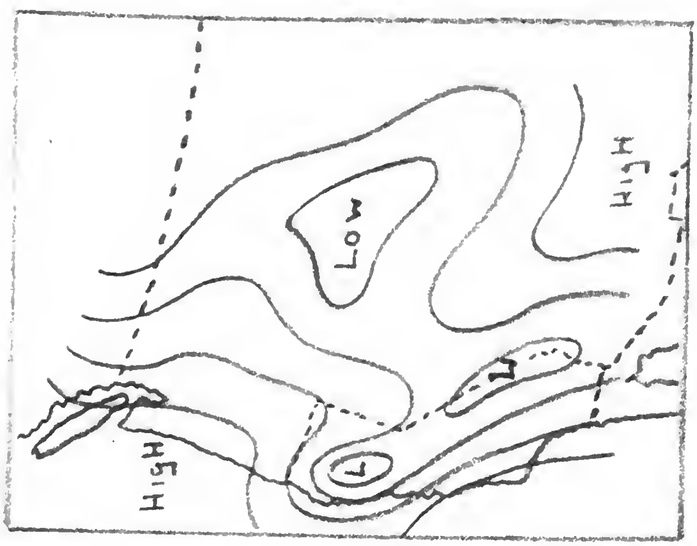


San Francisco Bay Region and Routes for Ingress of Marine Air

Figure 4



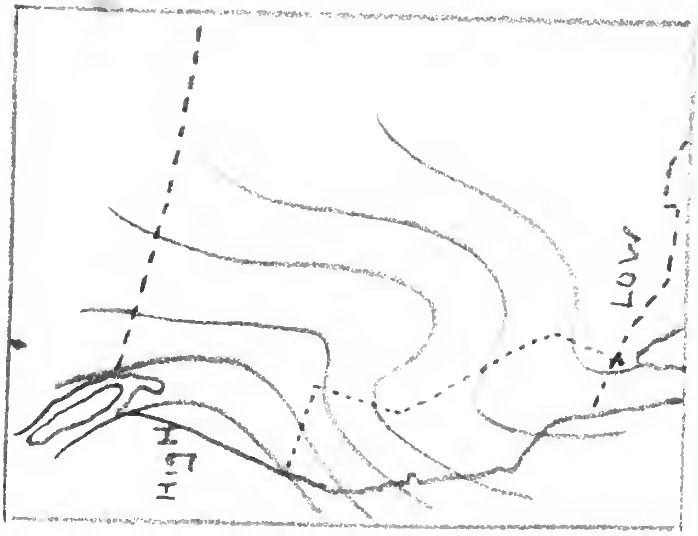
Favorable for stratus patches on California coast.



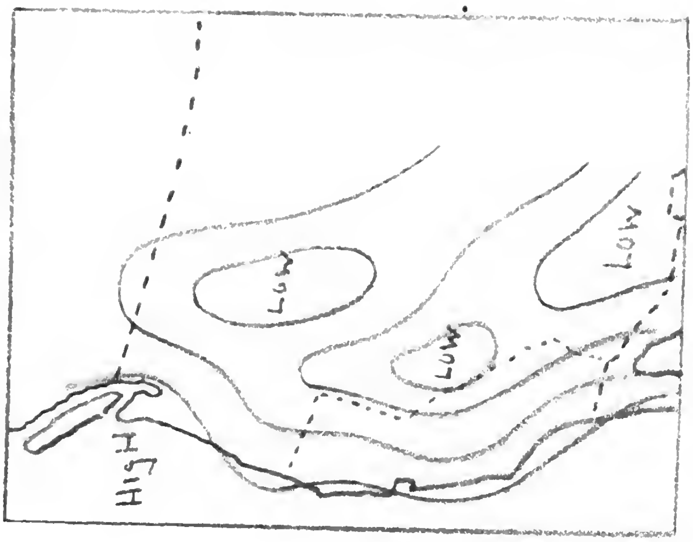
Favorable for stratus on California coast North of Point Arguello.

Typical Sea-Level Pressure Patterns

Figure 5



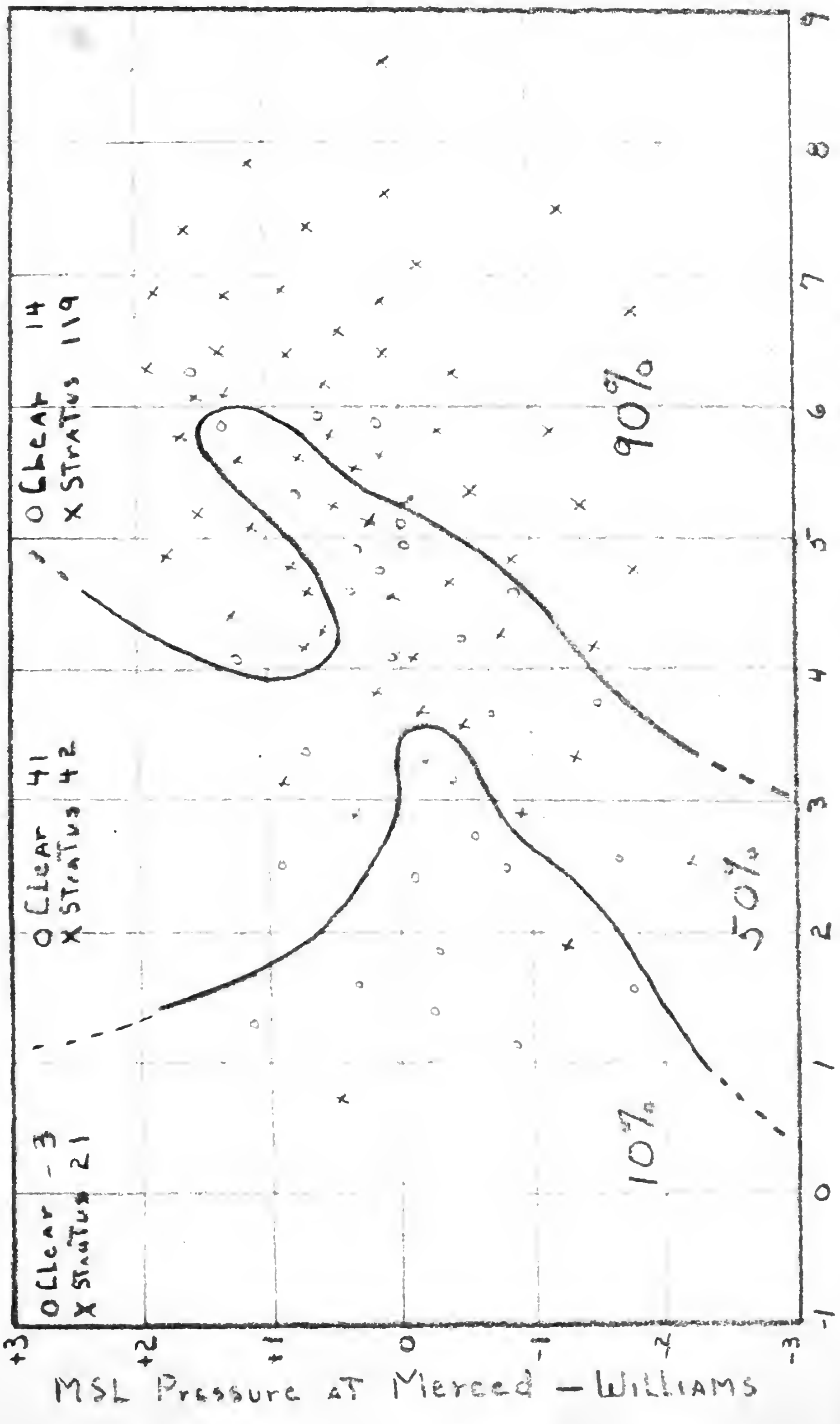
Not favorable for stratus formation on California coast.



Favorable for stratus on entire California coast.

Typical Sea-Level Pressure Patterns

Figure 6



Pressure Difference

Figure 7

area. Therefore, there should be a typical pressure difference between stations in this area that would indicate the type of pressure pattern that dominates for stratus occurrence. In the investigation three stations were used for setting up such pressure-difference indices; Williams in north central California, Farallons Islands thirty miles west of Golden Gate, and Merced in central California. The months of May to October 1949 and 1950 inclusive were used, with the exception of September 1949. This month was omitted, so as to have some independent test data. Also in the statistical analysis, those cases in which a front was approaching the Bay area or a deep low pressure cell lay west of the Bay area were omitted. By definition, the forecast period commences at 1600 PST of the day the forecast is made, lasting twenty four hours, until 1600 PST of the following day. The weather is classified either as clear or stratus. Stratus verifies if any low clouds or fog is reported at San Francisco, Alameda, Oakland, Moffett Field and San Rafael. Clear verifies if no low clouds are reported at any of these stations during the forecast period, or if only high or middle clouds are reported. In constructing the pressure-difference diagram, Figure 7, the following two parameters were: pressure difference between Farallons minus Williams, and that for Merced minus Williams, against which was plotted the verifying weather of the forecast period.

5. Other Investigations Taken.

Several other investigations were taken with the object of building additional scatter diagrams that could be used in the forecasting of stratus. One of these was plotting a wind-rose of 1300 PST one thousand foot winds at Alameda against the verifying weather for the forecast period. This resulted in too great a scatter to be conclusive, as can be seen from Figure 8.

Following this the 0700 PST one thousand foot winds at Alameda were plotted against the verifying weather for the forecast period. Figure 9 was the result. Although the scattering here is good, when used as a forecasting tool, it did not give as good results as the method finally adopted.

At this point Figure 7 was again consulted and it was decided to investigate those cases falling in the 50% zone. These cases were separated by whether the Farallons 1600 PST synoptic report showed clear or stratus. Any amount of stratus or fog made it a stratus case. Being thus separated the verifying weather of these cases was then plotted against the base of the inversion as obtained from the morning 0700 PST Oakland radiosonde. Figure 10 was the result. As can be seen there is a good percentage of clear for the forecast period whenever the Farallons reported clear and the base of the inversion is at 1100 feet or below. It was therefore decided to use this as the criterion for the 50% cases in the Pressure-Difference Diagram, Figure 7.

To further substantiate this 1100 foot criteria, the cases under consideration showed an average temperature of about 60° F (15.6° C) at the Farallons at 1600 local. The average dew point was about 56° F (13.3° C). Using standard atmosphere pressure (1013.3 mb) for mean sea level, the lifting condensation level on a pseudo-adiabatic chart, was found to be at about 975 mb. as shown in Figure 11. The height of this level as interpolated from the U. S. Standard Atmosphere Tables is approximately 1,070 feet. This is fairly close to the 1100 foot criteria.

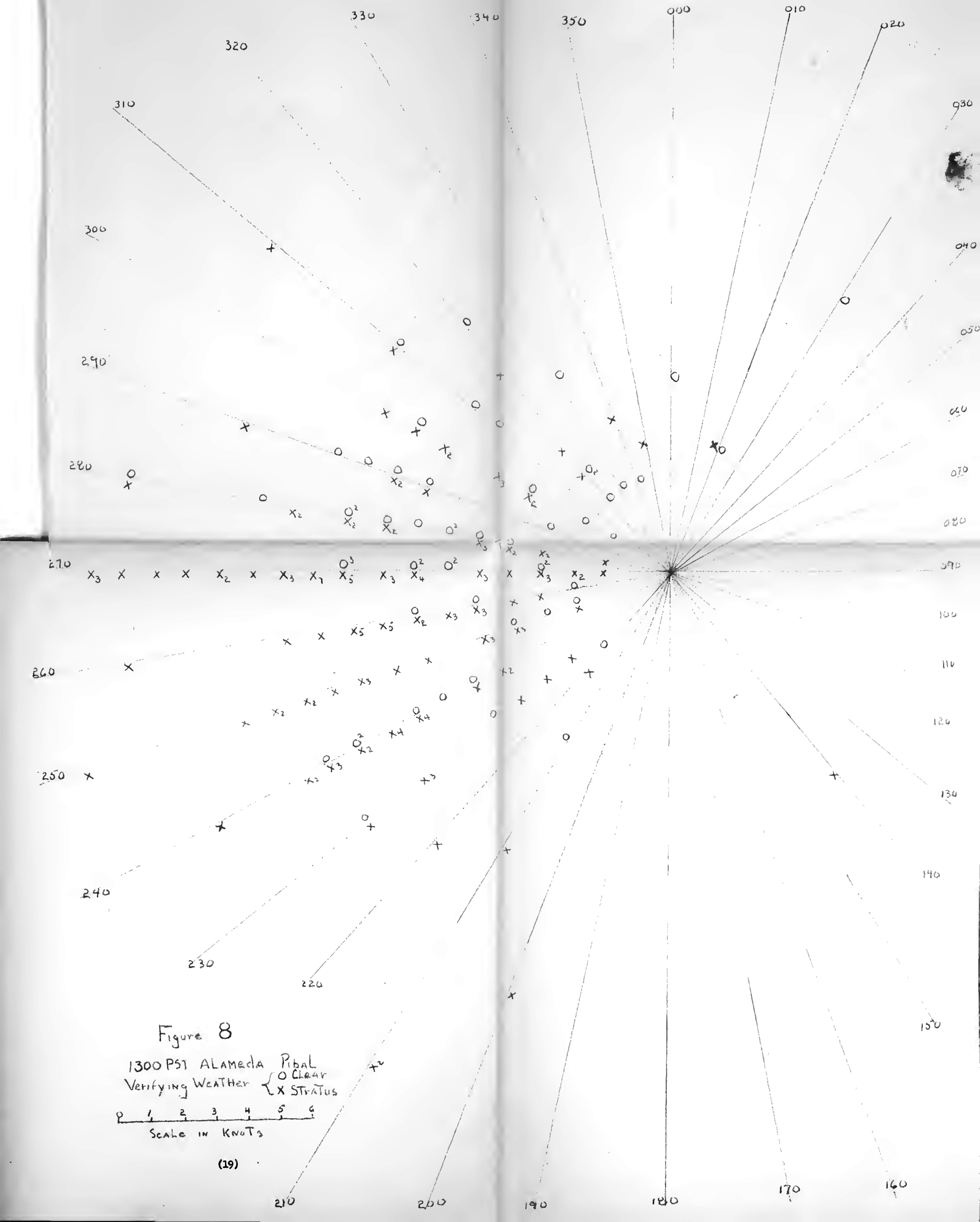


Figure 8

1300 PST Alameda Pibal
Verifying Weather { O Clear
X Stratus }

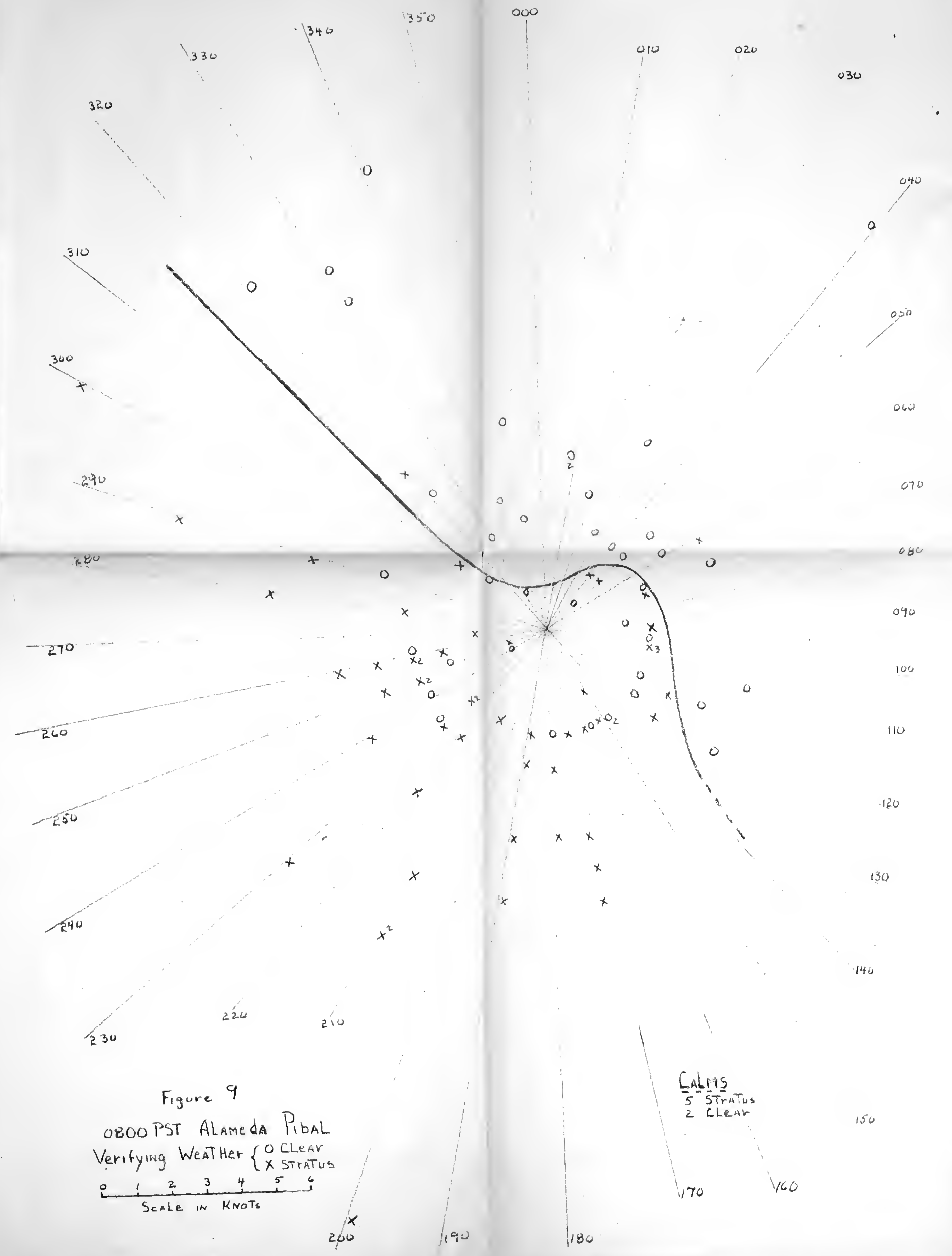


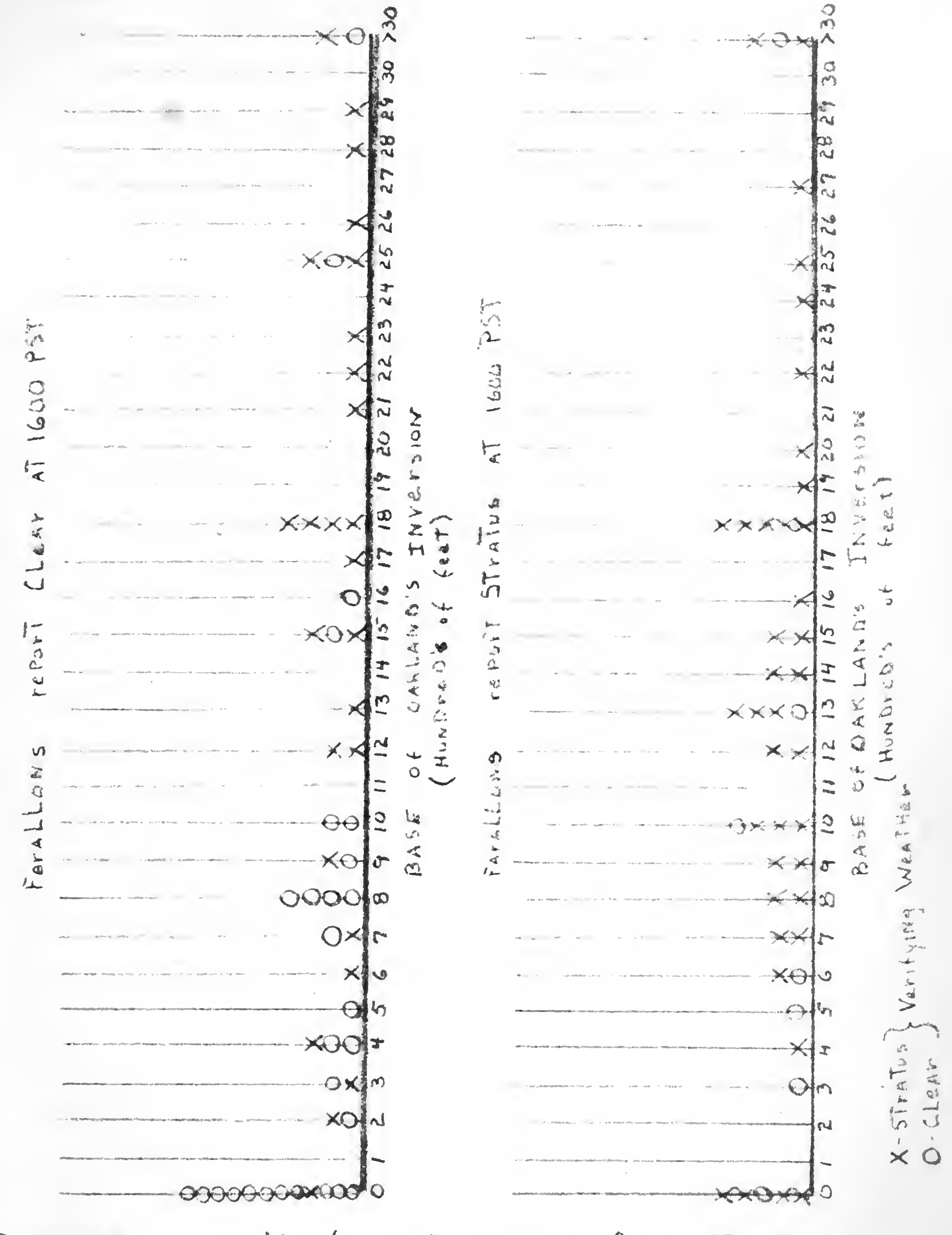
Figure 9

0800 PST Alameda Pibal

Verifying Weather { O Clear X Stratus

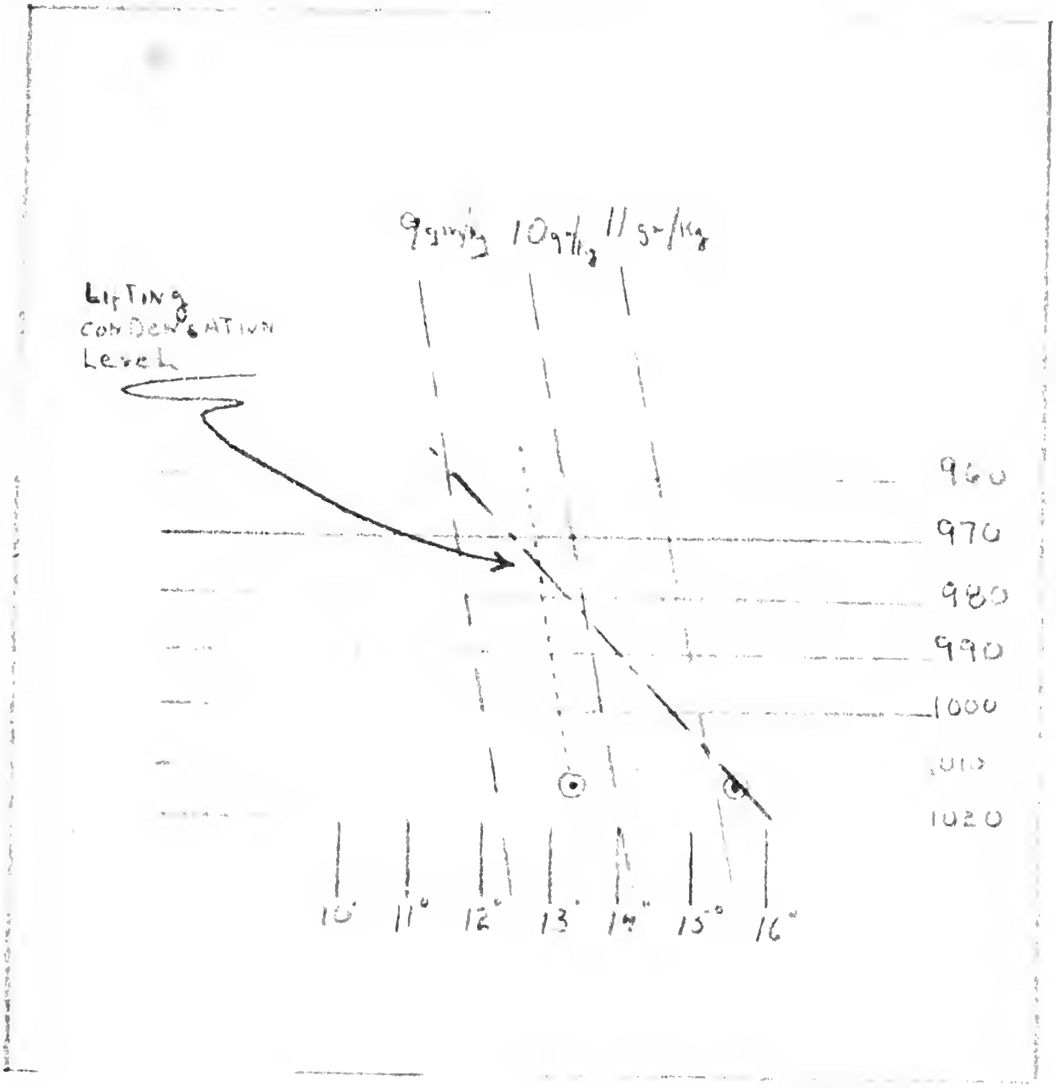
0 1 2 3 4 5 6

Scale in Knots



Distribution of Verifying Weather Against Base of the Inversion and Farallons Weather

Figure 10



Average Temperature, Dew Point and Lifting Condensation Level Plotted on a Pseudo-Adiabatic Chart

Figure 11

III. RESULTS AND CONCLUSIONS

1. An Objective Method.

As has been previously stated, Figure 7, the pressure difference diagram is the main basis of this forecasting method, since it indicates the flow pattern. Therefore, on the late afternoon of the day a forecast is to be made, one obtains the three mean sea level pressure reports from Williams (ILA), Merced (MER) and the Farallons (495) for 1600 PST. Obtain two parameters by subtracting the Williams pressure from that of the Farallons and Merced. With these two parameters enter Figure 7. If the point of intersection falls in the 90% zone, forecast stratus to occur that night and following morning. If the intersection falls in the 10% zone, forecast clear. However, if the intersection lies in the 50% zone a further criteria are needed and here one uses Figure 10. This figure tells us that if the 1600 local Farallons report is clear (no stratus or fog) and the base of the inversion at Oakland that morning (0700 PST, which is the latest available) is below 1100 feet forecast clear. Otherwise forecast stratus.

Now, having set up our method, let us make a check on it. As was previously stated May to October 1949 and 1950 exclusive of September 1949 were used to construct the pressure difference diagram. Thus the objective method was used on this data, excluding September 1949. The tetrachoric correlation Table 1 was obtained.

		Forecasted in S. F. Bay Area: Stratus	No Stratus	
Observed in S. F. Bay Area	Stratus	167	10	177
	No Stratus	22	41	63
		189	51	240

TETRACHORIC CORRELATION OF FORECAST FREQUENCIES

TABLE 1.

The percentage of correct forecasts from this data is $\frac{208}{240} = 86.7\%$. However, it is still necessary to determine a skill score on this data to show if the objective method is better than pure chance. The skill score as generally defined is $S_c = \frac{C - E(c)}{N - E(c)}$, where C is the number of correct forecasts, E(c) the number of forecasts expected to be correct due to chance, and N the total number of forecasts. The frequency of occurrence of stratus ($\frac{177}{240} = .7375$) was obtained from the data used. From this was obtained the following skill score: $S_c = \frac{208 - 152.8}{240 - 152.8} = 0.63$

A further test to show if this forecast method is better than chance is to use a Chi Square test, (Kenny [3]), using the following form:

$$\text{Chi Square} = \frac{(\text{Frequency of observed} - \text{Frequency of Theoretical})^2}{\text{Frequency Theoretical}}$$

$$\text{Chi Square} = \frac{(167 - 139.4)^2}{139.4} + \frac{(22 - 49.6)^2}{49.6} + \frac{(10-37.6)^2}{37.6} + \frac{(41 - 13.4)^2}{13.4}$$

Chi Square = 98.0617

The Chi Square is a Null-Hypothesis test. In this case the Null-Hypothesis is: There is no difference between the forecast frequency of chance and forecast frequency resulting from the forecast method. Since there is only one degree of freedom in a tehrachoric correlation the 5% level of belief requires Chi Square equal to 3.84 or less, (Kenny [3]) and the 1% level requires Chi Square equal to 6.63 or less to accept the Null-Hypothesis. 98.0617 was the value obtained which far exceeds even the 1% level of belief, thus rejecting the Null-Hypothesis. Thus the forecast method is much better than chance.

Now using September 1949 test data the distribution in Table 2 was obtained:

		Forecasted in S. F. Bay Area		
		Stratus	No Stratus	
Observed in	Stratus	13	2	15
S. F. Bay Area	No Stratus	1	7	8
		14	9	23

TETRACHORIC CORRELATION OF FORECASTS OF SEPTEMBER 1949

TABLE 2.

The percentage of correct forecasts from this data is $\frac{20}{23} = 86.9\%$

Now using a skill score on this data and using the same frequency of occurrence of stratus (.7375) that was obtained from the larger sample of data we get

$$S_o = \frac{20 - (14 \times .7375 + 9 \times .2625)}{23 - (14 \times .7375 + 9 \times .2625)} = 0.71$$

2. A Comparison to Persistency Method of Forecasting.

At this point it is advisable to examine persistency. It is known that persistency is a very real meteorological phenomenon and should be considered in the development of any objective forecasting method. A knowledge of the persistency is essential to evaluate properly the skill of a forecasting method as evidenced by the skill score, that is,the skill score attained by persistency should be subtracted from the skill score of a forecast method to indicate the effectiveness of the method. If this difference is negative the method is not showing worthwhile skill.

To obtain an estimated skill score of persistency we can estimate the score for a 30 day month (Jorgensen [2]). For such a month we have an average number of 2.9 clear periods per month. This figure of 2.9 periods was obtained from all the data under consideration. Assuming a missed forecast at the beginning and end of each period, the total misses per month would be 5.8. Then the number of correct forecasts for a 30 day month would be (30 - 5.8) = 24.2. Due to the fact that we assumed persistence as our forecasting method we would have the same number of forecasts of clear as observations of clear and the same number of stratus forecasts as stratus observations.

Using the same frequency of stratus occurrence as before (.7375) we get the expected number of correct forecast on the basis of chance to be,

$$E(c) = .7375 \times 30(.7375) + .2625 \times 30(.2625)$$

$$E(c) = 18.43$$

With this data the skill score for persistence would be:

$$S_c = \frac{C - E(c)}{N - E(c)} = \frac{24.2 - 18.43}{30 - 18.43} = .49$$

The difference between the persistence skill score (.49) and the objective method's skill score (.63) is + 0.14. Although this is not very large it does show that the method presented here is better than persistence. This is a greater achievement than is at first apparent, when it is recalled that on the basis of persistence, one would verify 24.2 out of 30 forecasts, on the average.

3. A Second Objective Method.

As was mentioned previously the 0700 PST one thousand foot Alameda wind showed a trend when plotted against the verifying weather (Figure 9). Therefore another forecast was made. The same data, excluding September 1949, was used first on the pressure diagram (Figure 7); then if in the 50% zone, the 1100 foot criterion of Figure 10 was used. Then, if one "fell" in the "Farallons clear, base of inversion less than 1100 foot" zone, the pibal diagram (Figure 9) was checked in an effort to reduce the forecasting error of the 1100 foot criterion. Table 3 was the result of this procedure.

		Forecasted in S. F. Bay Area		
		Stratus	No Stratus	
Observed in	Stratus	168	9	177
S. F. Bay Area	No Stratus	27	36	63
		195	45	240

TETRACHORIC CORRELATION OF THE SECOND OBJECTIVE METHOD

TABLE 3.

This gave the following skill score:

$$S_c = \frac{204 - 155.6}{240 - 155.6} = .57$$

which gives a lesser skill score than the first forecasting method. The probable reason for this, even though the morning pibals do show an apparent indication toward verifying stratus or clear, is that the 0700 PST pibals are based on too few actual reports, and then mainly on cases of which the previous night was clear. Most of the 0700 PST pibals were reported PICO, so that the sample of events used in constructing Figure 9 represents a biased sample.

4. Conclusions.

This thesis demonstrates the feasibility of devising an objective forecast technique utilizing basic circulation parameters.

It is clear that persistence plays an important part in the forecasting of summer stratus, for not only does persistence give a skill score of .49, but also persistence has been utilized as a forecast tool. In this connection it should be recalled for those cases in the 50% zone of Figure 7, the forecast is based largely (Figure 10) on the current weather at a key station to the west, Farallons Island.

The forecasting method offered herein is satisfactory but several refinements can be made. Among them are: forecasting the time of formation and time of breaking of the stratus; the amount of sky coverage; forecasting for one station in particular.

BIBLIOGRAPHY

1. Byers, H. R. Summer Sea Fogs of the Central California Coast. University of California Publications in Geography. Vol 3, No. 5, 1930.

2. Jorgensen, D. L. Persistency of Rain and No-Rain Periods During the Winter at San Francisco. Monthly Weather Review, Vol 77, November 1949. Washington, U. S. Government Printing Office, 1949.

3. Kenny, J. F. Mathematics of Statistics. New York, D. Van Nostrand, 1939.

4. Neiburger, M. Temperature Changes During Formation and Dissipation of West Coast Stratus. Washington, D. C., U. S. Department of Commerce. Weather Bureau. July, 1944 (Weather Bureau Research Paper No. 19).

5. Neiburger, M., Beer, G. P., and Leopold, L. B. The California Stratus Investigation of 1944. Washington, D. C., U. S. Department of Commerce, Weather Bureau, April 1945.

6. Petterssen, S. On the Causes and the Forecasting of the California Fog. American Meteorological Society, Bulletin. 19:49-55, February, 1938.

7. Scripps Institution of Oceanography, University of California. Fog Forecasting on Coasts. Office of Naval Research, Fog Project Report No. 3. August, 1948.

8. Steffan, H. C. and Morgan, J. H. Stratus Ceilings at San Francisco Airport. Weather Bureau Airport Station, San Bruno, California. 1944. (Unpublished Paper).

9. Stocker, G. H. Forecasting Bay Region Stratus. Journal of Aeronautical Meteorology. Vol. 1, No. 4. July, 1945. Meteorological Committee of the Air Transport Association of America, 129-139. July, 1945.

10. Taylor, G. L. The Formation of Fog and Mist. Quarterly Journal of the Royal Meteorological Society, 43: 241-268, 1917.

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